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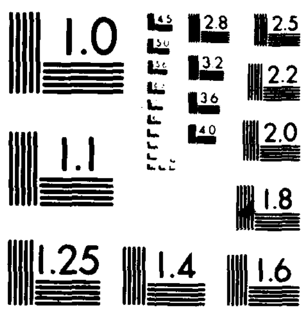
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The research performed during the course of this Grant included both analysis of previously obtained data and additional experimental work. The principal experimental work involved the preparation and launching of rocket payloads during two solar eclipse expeditions: to Northern Ontario in February, 1979 and to Kenya in February, 1980. These payloads used "blunt" conductivity probes to measure atmospheric conductivity, and the changes in conductivity produced by lamps built into the payloads, both visible and ultraviolet.

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Final Report

ARO-D Grant No. DAAG29-78-G-0129

U.S. Army Research Office

Research Triangle Park, North Carolina

Submitted by

Leslie C. Hale, Principal Investigator

Ionosphere Research Laboratory
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October 1, 1981

INTRODUCTION

This is the final report on research done on Grant No. DAAG29-78-G-0129, covering the period of 10 June 1978 to 9 December, 1980. The report consists of a resume of the research performed, a list of scientific personnel, a manuscript of a paper summarizing scientific findings, abstracts of two papers presented at scientific meetings but not prepared for publication, and a reprint of a paper summarizing data obtained.

RESUME OF RESEARCH

The research performed during the course of this Grant included both analysis of previously obtained data and additional experimental work. The principal experimental work involved the preparation and launching of rocket payloads during two solar eclipse expeditions: to Northern Ontario in February, 1979 and to Kenya in February, 1980.

These payloads used "blunt" conductivity probes to measure atmospheric conductivity, and the changes in conductivity produced by lamps built into the payloads, both visible and ultraviolet. A prototype was built and launched on a balloon during the "Atmospheric Electricity Workshop" in Laramie, Wyoming during the summer of 1978. The payload apparently performed satisfactorily but due to a failure in telemetry no data were received. This work did provide the development necessary for the construction of four rocket payloads, all of which were launched successfully, including one that was relaunched after recovery.

Two payloads were prepared and launched during a solar eclipse expedition to Northern Ontario in February, 1979. The first of these was launched during eclipse totality and the second the morning after, both under highly disturbed conditions. The data show little effects of changes in ionization rate but do show some rapid attachment during totality in a layer near 80 km. The data were summarized in a presentation to a Solar Eclipse Workshop in Las Cruces, N.M., in September, 1979, and in a report resulting from this meeting edited by Warren Berning, and in a subsequent report by John D. Mitchell (Report to ASL, March 31, 1981).

One result of the Ontario operation was that the high intensity (200 watts) quartz halogen lamp battery produced no detectable effect on ionization parameters (we expected this, but believe it had never been checked) so subsequent payloads omitted the visible lamps.

The next launch was from Wallops Island on September 16, 1979 as part of an Electrodynamics Series. This provides a mid-latitude baseline. This payload contained hydrogen, xenon, and krypton lamps to provide different wavelengths of ionizing radiation. (For high reliability, the eclipse payloads contained only krypton lamps). This payload was air-snatched and refurbished for the subsequent Kenya eclipse operation.

The data from the shots above and some earlier shots were summarized in a paper presented at the IUGG Symposium on the Middle Atmosphere in Canberra, Australia in December, 1979. This paper is included in this report.

The final operation supported by this grant was the launch of two payloads during a solar eclipse expedition to Kenya in February, 1980. The eclipse totality showed the complete attachment of electrons in the mesosphere during totality but the positive ion density did not approach the very low values seen on a succeeding shot at night.

The total conductivity data from the five launches above is summarized in a paper in August, 1981 Geophysical Research Letters.

SCIENTIFIC PERSONNEL

Professor Leslie C. Hale, Principal Investigator

Dr. Charles L. Croskey, Research Associate

David F. Young, Received M.S. in Meteorology

Michael R. James Received M.S. in Electrical Engineering

Jamshid Goshtabi, M.S. in Electrical Engineering

ELECTRICAL RESPONSE OF THE MIDDLE ATMOSPHERE

L. C. Hale and C. L. Croskey (both at the Ionosphere Research Laboratory and Electrical Engineering Department, Pennsylvania State University, University Park, Pennsylvania 16802 USA)

We consider the variability of electrical parameters of the "middle atmosphere" in response to various stimuli.

Figure 1 shows typical profiles of the positive component of electrical conductivity, compared with an extrapolation made by Gish before data were available above 30 km. [1,2]. This extrapolation is consistent with a model involving cosmic ray ionization and a simple gaseous chemical model. The (typical) enhanced "auroral" and "PCA" data can be explained by a simple chemistry model and enhanced ionization production due to these events. The decreased low latitude conductivities at lower altitudes reflect reduced cosmic ray ionization. The low latitude data is so far the only data to indicate a clearly defined wave-like structure. The most difficult data to explain is the large deviation below the Gish model between 40 and 70 km. at mid-latitudes. This was first observed in 1950 and explained by Bourdeau, Whipple and Clark [3] as due to "aerosol" particles. Subsequent data and analysis have supported this view, although the aerosol particles involved are extremely small (<10nm) and may perhaps be more correctly described as molecular aggregates or large clusters [4].

In Figure 2, the wide variability encountered in mid-latitude conductivity data is shown [1,2]. The difference in the positive conductivity on "non-anomalous" days measured at approximately the same solar zenith angle between $\sim$40 and $\sim$60 km. (curves 2 and 3-labelled T) was found to correlate extremely well ($r>.9$) with measured atmospheric temperature, with a temperature coefficient of $\sim 4\%/^{o}K$ above $\sim$40 km. [5]. This is far too high to be explained by gaseous phenomena, and lends support to the "solid-state" hypothesis, as due to a strong dependence of the size of the aerosol particles on temperature, thus varying the mobility of such cluster ions, possibly due to their shedding of a water or ice coating [4]. The altitude of the "knee" in the conductivity profiles and the variability of the conductivity above that altitude (labelled NO) has been attributed to variations in the nitric oxide density, which tends to occur during the "winter variability" period [1,2]. A combination of enhanced NO and depleted aerosol density is indicated in the curve (4) depicting a "winter anomaly" situation. The lowest conductivity (Curve 1) observed near sunrise indicates that the aerosol/clusters may greatly increase in size at night [6]. Curves 5D(day) and 5N(night) show the large enhancement in positive conductivity that has been produced in the stratosphere with in-situ ultraviolet (krypton) lamps capable of ionizing NO_x but no other known gaseous constituent of stratospheric air [7]. This indicates the presence of a relatively large quantity of an ionizable constituent with a product of density and ionization cross section (estimated at $\sim 10^{-9} cm^{-1}$) much greater than generally expected for NO_x. The fact that the UV lamp ionization cuts off sharply above $\sim$40 km. in the daytime taken with the fact that it continues to higher altitudes at night indicate that the threshold for ionization

PRESENTED TO IUGG SYMPOSIUM ON THE MIDDLE ATMOSPHERE, CANBERRA, DECEMBER, 1979, PUBLISHED IN CONFERENCE PROCEEDINGS, S. RUTTENBERG, ED., BOULDER, 1981.

(or possibly dissociation of large clusters creating higher mobility ions) is at a wavelength which normally penetrates to ~40 km. Curve 6 shows a rapid increase above about 40 km. in the daytime negative conductivity, indicating the presence of free electrons. An explanation for all of these data involves the presence of large numbers (>10^3/cc) of the aerosol/clusters throughout the mesosphere and stratosphere which are affected by UV normally penetrating to ~40 km. in the daytime.

Figure 3 shows a series of 4 electric field measurements taken before and during a geomagneticaly disturbed period in Alaska during operation "Aurorozone II." The "quiet" data shows an enhanced mesospheric field, which was subsequently "shorted" by enhanced ionizing radiation. During the most "disturbed" period (as determined by visible aurora and a riometer) this was accompanied by an enhancement in the lower stratosphere field [8]. The 40-60 km. ionizing radiation was found by Barcus, et al. (this volume) to be primarily due to X-rays during this "disturbed" measurement but mostly due to relativistic electrons when the electric field subsequently demonstrated a "reversal." This may have been caused by field lines from the deeply penetrating "REP event" electrons reconnecting to the earth, which may be closer to the injected electrons than similarly highly polarizable (σ/ϵ) regions of the ionosphere. The "day" data shows this reversal, but may be complicated by sunrise effects.

The "Aurorozone II" data was taken during a geomagnetic "event" characterized by magnetic activity, doubling of the solar wind speed, and other phenomena, but with relatively little effect on high energy cosmic ray flux (Figure 4). During a similar event in August 1976 a series of conductivity measurements were made (Figure 5). They showed that subsequent to the onset of the event the middle atmosphere the conductivity profiles appeared to return to a state closer to the Gish extrapolation, with σ+ increasing and σ- decreasing, indicating more "gaseous" behavior. This shows that the penetration of such effects to mid-latitudes may involve the depletion in size or number of the aerosol/clusters in the middle atmosphere.

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This research was supported by ARO, ONR and NASA.

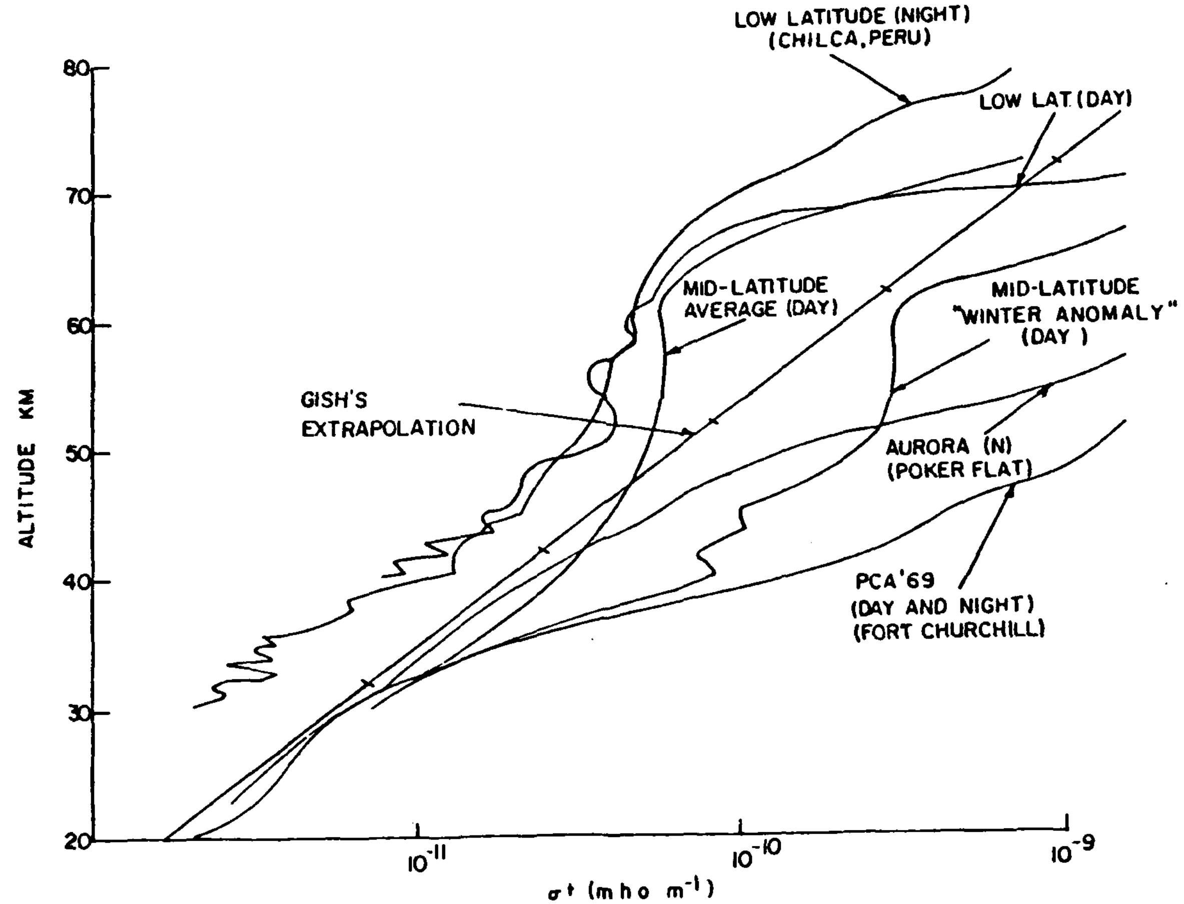

Figure 1: POSITIVE CONDUCTIVITY UNDER VARIOUS GEOPHYSICAL CONDITIONS

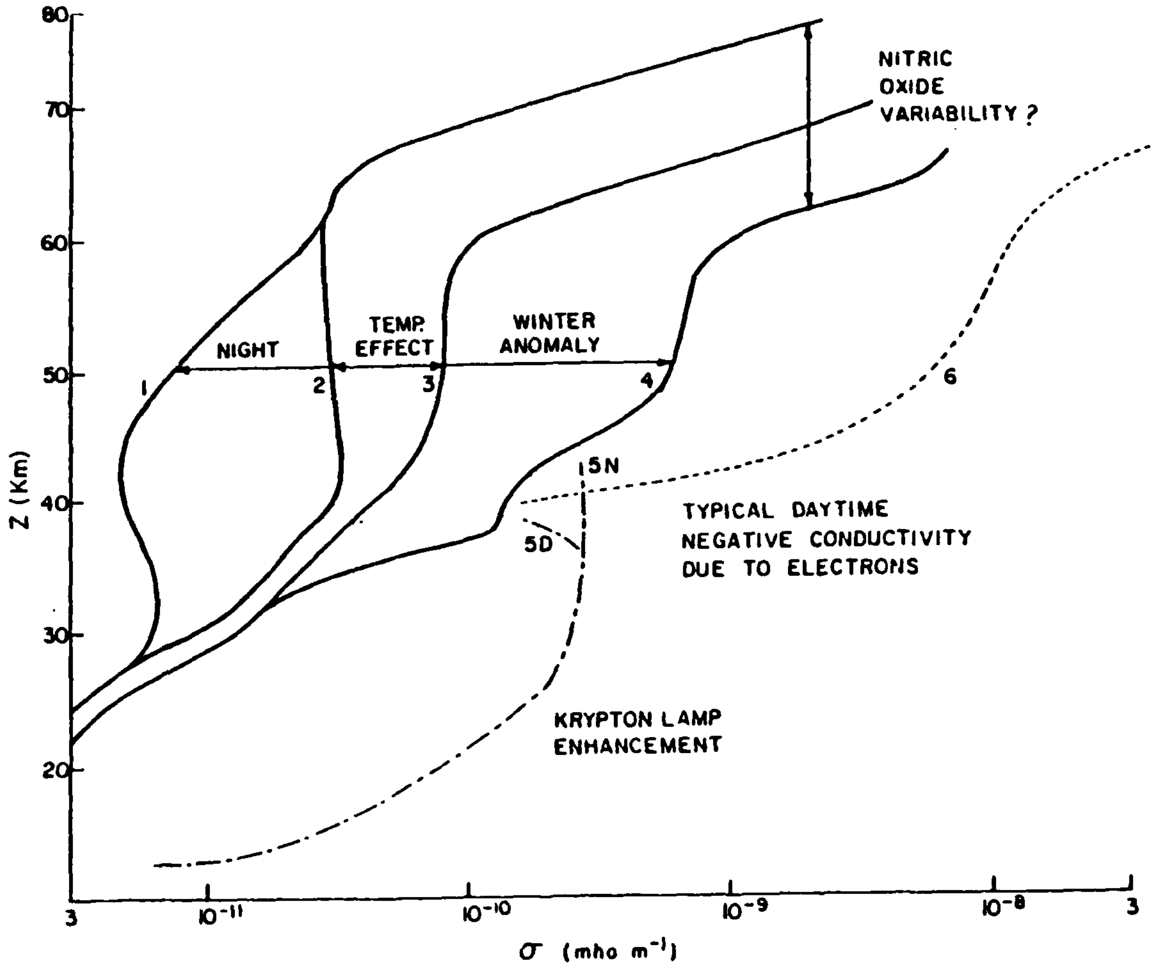

Figure 2: VARIABILITY OF CONDUCTIVITY AT MID-LATITUDES

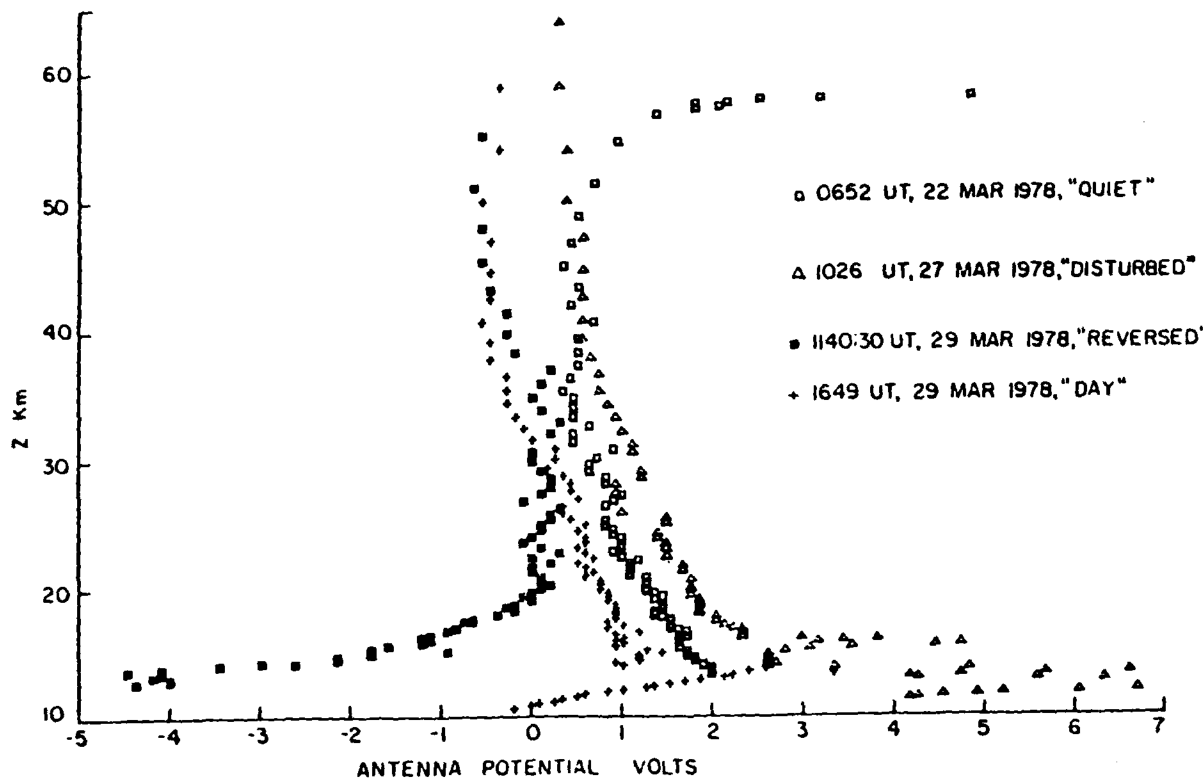

Figure 3: ~ DOWNWARD ELECTRIC FIELD (VOLTS/METER) DURING "AURORAZONE II"

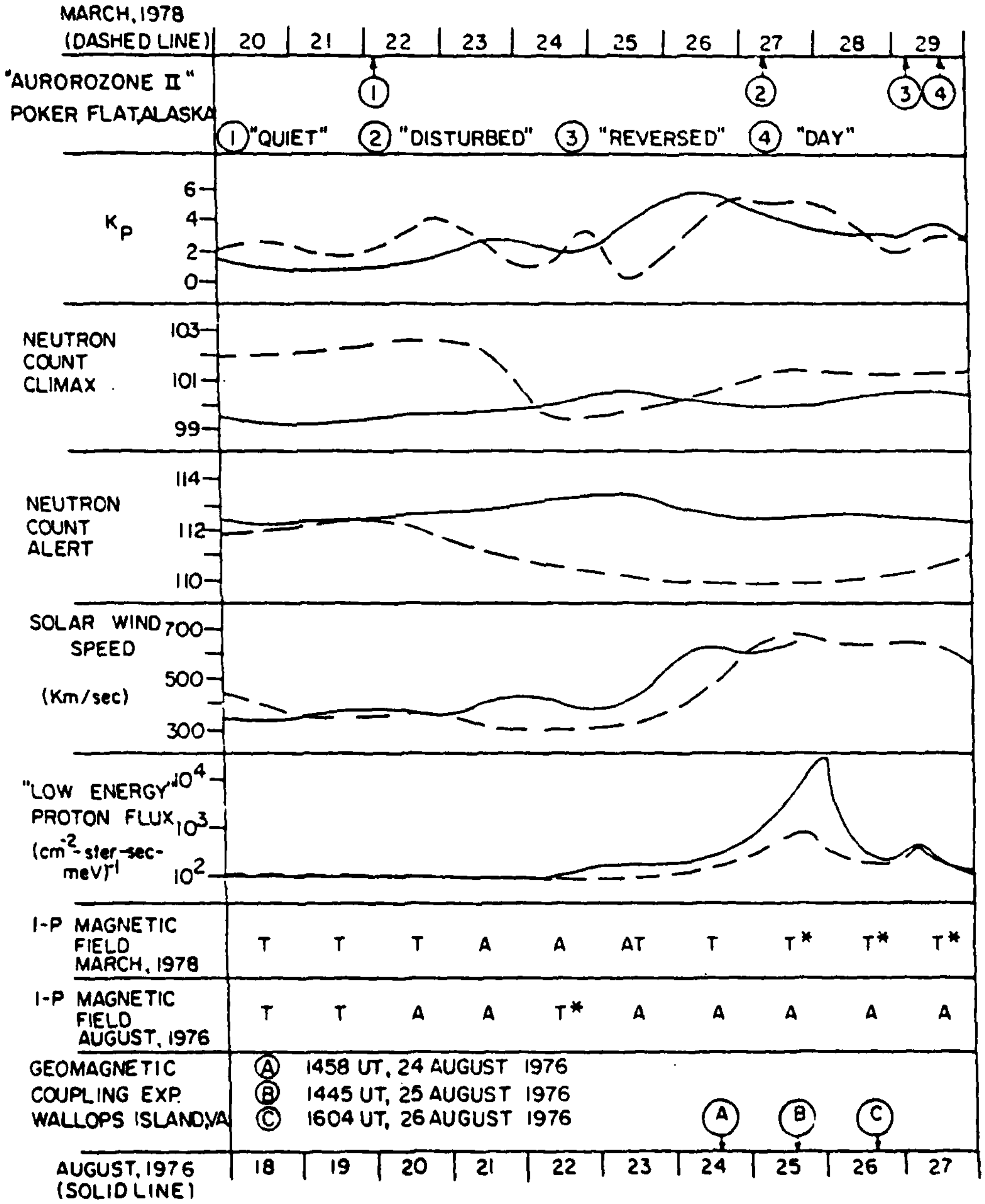

Figure 4: GEOPHYSICAL CONDITIONS FOR "AURORОZONE II" AND "GEOMAGNETIC COUPLING EXPERIMENT"

This figure was prepared by David F. Young from Solar Geophysical Data (Boulder).

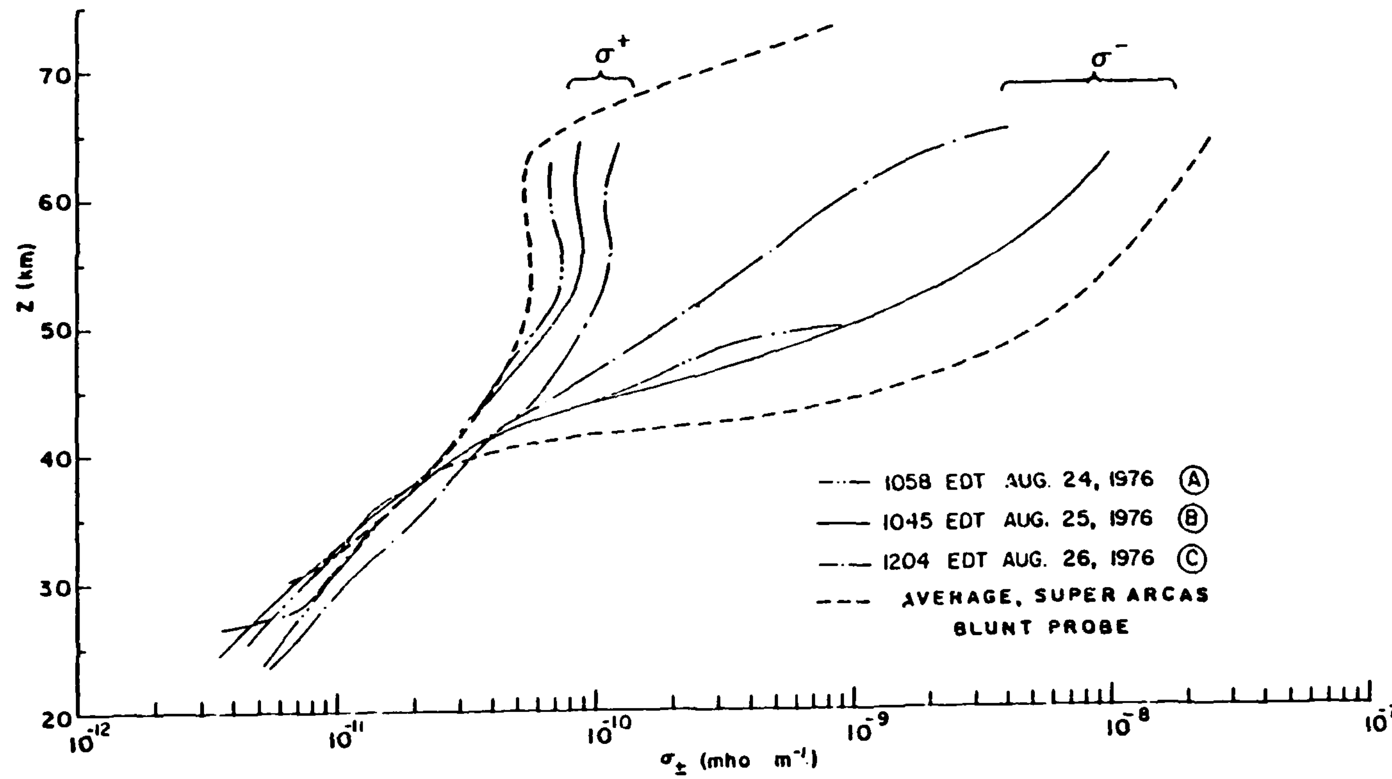

Figure 5: CONDUCTIVITY VARIATION DURING "GEOMAGNETIC COUPLING EXPERIMENT"

ATMOSPHERIC ELECTRICAL MEASUREMENTS FROM SOLAR ECLIPSE EXPEDITIONS

L. C. Hale, C. L. Croskey (both from the Ionosphere Research Laboratory, The Pennsylvania State University, University Park, Pennsylvania 16802)

Four Astrobee-D rockets carrying parachute borne payloads were launched during totality and the succeeding nights during eclipse expeditions to Northern Ontario in February, 1979 and Kenya (San Marco Range) in February, 1980. The payloads contained blunt conductivity probes, ultra-violet (Krypton) lamps, and electric field antennas. The Canadian payloads also contained 200 watt "visible" lamps.

The Canadian rockets were launched near Red Lake, Ontario. Strong auroral particle precipitation prevented the observation of definite eclipse effects. The "visible" lamps produced no effects on ionization at any altitude in the data range of 20 to 87 km. A nighttime (pre-sunrise) launch showed UV lamp effects to a much higher altitude than observed in similar daytime data.

The eclipse and night conductivity data from both expeditions are compared with previous data and implications to photo-ionization and photodetachment rates are discussed.

The electric field data are compared to a similar measurement made at Wallops Island on September 16, 1979 and provide a high-mid-low latitude comparison. Tentatively, the data confirm the existence of a "global" mesospheric circuit.

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2. 1980 Spring Meeting
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5. No
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7. None

PRESENTED AT 1980 SPRING AGU MEETING
IN TORONTO, MAY, 1980

SUB-CENTIMICRON AEROSOL PARTICLE EFFECTS ON ATMOSPHERIC ELECTRICITY

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There is extensive evidence that large numbers of molecular aggregates ($\sim 10^3$/cc, < 10 nm dia.) permeate the atmosphere up to about the mesopause. The origin of these particles is probably extraterrestrial, they may be ice or water coated, and they are in generally downwards flow. Under quiet mid-latitude conditions they dominate ionization phenomena above about 40 km but in the presence of enhanced ionizing radiation this altitude can be much lower. Certain types of "anomalous" winter conditions, including stratospheric warmings, may be accompanied by their break-up, resulting in the release of water vapor (relatively more at higher altitudes), altered radiation balance, and a return to gaseous domination of ionization processes. In the upper mesosphere their relatively large momentum transfer cross section make ionized particles effective in dynamo/motor processes and may give rise to a "global" mesospheric circuit. The coupling of "impulsive" charge separation phenomena such as relativistic electron precipitation or lightning strokes to the global circuit may depend on the electrical conductivity at higher altitudes than those determining the "column resistance", and hence on the variability due to the aerosol/clusters and to solar/geomagnetic activity. The latter may also alter the flow of particles in the global field by affecting processes which determine their net average charge.

INVITED PAPER PRESENTED AT VITH INTERNATIONAL SYMPOSIUM ON ATMOSPHERIC ELECTRICITY, MANCHESTER, ENGLAND, JULY, 1980

GEOPHYSICAL RESEARCH LETTERS, VOL. 8, NO. 8, PAGES 927-930, AUGUST 1981

MEASUREMENTS OF MIDDLE-ATMOSPHERE ELECTRIC FIELDS AND ASSOCIATED ELECTRICAL CONDUCTIVITIES

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Abstract. A simple antenna for measuring the vertical electric field in the "middle atmosphere" has been flown on a number of rocket-launched parachute-borne payloads. We present here the data from the first nine such flights, launched under a variety of geophysical conditions, along with electrical conductivities measured simultaneously. The data include indications of layered peaks of several volts per meter in the mesospheric field at high and low latitudes in situations of relatively low conductivity. During an auroral "REP" event the electric field reversed direction in the lower stratosphere, accompanied by a substantial enhancement in conductivity. The data generally do not confirm speculations based only on the extension of the thunderstorm circuit from below or the mapping of ionospheric and magnetospheric fields from above, but seem to require, in addition, internal generation processes in the middle atmosphere.

Introduction

Electric fields in the earth's middle atmosphere, comprising the stratosphere and mesosphere, have not been measured extensively. Most of the concepts of middle atmosphere fields have been generated by speculation, primarily the extension of the "classical" thunderstorm circuit [e.g. Israël, 1973] to higher altitudes. The conductivity profiles used in such extrapolations have generally been assumed exponential profiles rather than actual measured values. Some balloon measurements of electric fields in the lower stratosphere [Olson, 1971; Mühleisen, et al., 1971] have appeared to necessitate a more complex scenario for their explanation under all conditions.

The first reported electric field measurements encompassing the stratosphere and mesosphere were made in the USSR [Bragin, et al., 1974]. Four electric field profiles, all of which indicated large layered "peaks" of several volts/meter in the mesospheric vertical field, led to the publication of a paper suggesting a permanent "Mesospheric Maximum of the Electric Field Strength" [Tyutin, 1976]. This result has generally been greeted with scepticism [Markson, reply to Hale, 1979; Bering et al., 1980]. However, we thought that the USSR results were worth checking, and undertook to add simple electric field antennas to a number of rocket payloads (see Figure 1). On each payload, a one-meter metallic braid antenna was placed around the nylon lanyard leading to the parachute which decelerates and orients the payload vertically. Although asymmetric, the electrodes so formed are relatively long and slender to minimize wake effects [Hale, reply to Bering et al., 1980]. The overall length of antenna plus payload was two meters, resulting in an effective dipole length of approximately one meter. Thus, the downward electric field in volts/meter is approximately equal to the antenna-to-payload potential in volts. This potential was measured using an electrometer follower and telemetered to a ground station. Absolute potential of the payloads was monitored by charged particle sensors on the payloads and was always found to be less than 0.3 volts in magnitude. We present here data from the first nine such launches, taken under a variety of conditions including geomagnetically "quiet", "disturbed", and a "REP" event at high latitudes; two different solar eclipses; quiet mid-latitude; and nighttime equatorial. Conjunctive conductivity data associated with these E-field profiles are presented and the implications of the data are discussed briefly.

Electric Field Data

Four of the systems shown in Figure 1a were flown on Super Arcas rockets during operation "Aurorozone II" at the Poker Flat Research Range near Fairbanks, Alaska. The payloads contained high energy particle and X-ray detectors and a Gerdien condenser for charged particle analysis [Goldberg, 1979]. The data from the first two of these [Hale and Croskey, 1979] showed evidence of large mesospheric electric fields (curve 1) during "quiet" conditions, but this feature vanished during disturbed conditions (curve 2) of intense aurora and over 5 dB of riometer absorption. Hale and Croskey [1979] and a subsequently published debate [Bering et al., 1980; reply by Hale, 1980] contain more discussion of the technique and its validity. Flights 1 - 4 attained relatively low altitudes and we cannot say whether unusual conditions such as peaks or reversals occurred at higher altitudes on these flights.

Curves 3 and 4 were taken during a relativistic electron precipitation (REP) event, at night (3) and on the following morning (4 - dashed because daytime data were considered suspect due to possible photoemission effects, although such effects are not obvious from the data). Curve 3 provides evidence for a "reversal" in the fair weather field associated with auroral activity, a rarely observed condition previously reported by Freier [1961] from surface observations and by Olson [1971] from balloon observations. Reversals are generally associated with thunderclouds, but Alaska was unusually clear of meteorological activity during the entire Aurorozone II period [Henry

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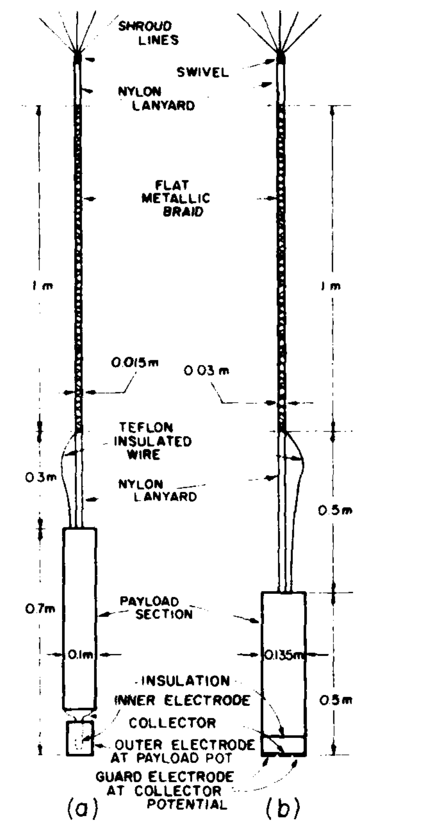

Figure 1. (a) Gerdien condenser (1-4) and (b) Blunt probe (5-9) payloads with electric field antennas.

Cole, formerly operational meteorologist with the Poker Flat Research Range, private communication].

The remaining five electric field profiles were obtained using the configuration of Figure 1b, launched by Astrobee-D rockets. The payloads also contained "blunt" conductivity probes as shown, and internal sources of ultra-violet radiation (which were switched off for the data presented here). Curves 5 and 6 were taken under moderately disturbed conditions during a solar eclipse expedition to the "Chukuni" launch range between Red Lake and Ear Falls, Ontario; curve 7, taken at Wallops Island, is the only mid-latitude data of this group; and curves 8 and 9 were taken during another solar eclipse expedition to the "San Marco" launch platform off the coast of Kenya. The deceleration systems failed during both eclipse totality shots (5 and 8) but the streaming parachutes vertically oriented the payloads, which were in totality for the entire data period for 5, and until below 15 km on 8. (The fact that the very much higher velocities of these streaming parachutes did not obviously affect the electric field data gives us some confidence that the technique is not very sensitive to velocity.) The post eclipse shots (6 and 9) show similar cusps at about 18 km even though they were launched at widely different times and locations.

Curves 2, 5, 6, 7, and 8 form a "rope" (circled) from below 40 km to their highest altitudes with an inferred electric field which is a substantial fraction of a volt/meter. Curves 3 and 4, during the "REP" event, show a similar displacement in the opposite direction. Curves 1 and 9, which indicate mesospheric peaks, both show smaller values than the "rope" at intermediate altitudes, with only 9 approaching zero field, within limits of error (± .1 volt), between 52 and 62 km. Field values below 15 km were suppressed because the high effective resistance of the antenna and payload to the atmosphere may degrade the accuracy of the measurement.

Electrical Conductivity Data

Total conductivities from the nine flights are shown in Figure 3. These were determined from Gerdien condenser data on the Aurorozone II flights (1-4) and blunt conductivity probes on flights 5-9. Curves 1-6 are typical high latitude conductivity profiles with a change in slope at about 50 km due to the influx of precipitated particles and bremsstrahlung at the higher altitudes [Mitchell, et al., 1981]. They vary from the relatively "quiet" condition of 1 to those due to the greatest influx of deeply penetrating high energy charged particles during a REP event (3). Ionization in the 40-60 km range was determined to be almost entirely due to relativistic electrons in 3, which is different from the "disturbed" conditions of 2 where the ionization in this altitude range was primarily due to bremsstrahlung from electrons stopping at higher altitudes [Barcus, et al., 1979]. Curve 7 is within the typical mid-latitude range which has been found to be highly variable above 40 km [Cipriano, et al., 1974], a result attributed to aerosol particles [Chesworth and Hale, 1974]. Curves 8 and 9 are low latitude results, with

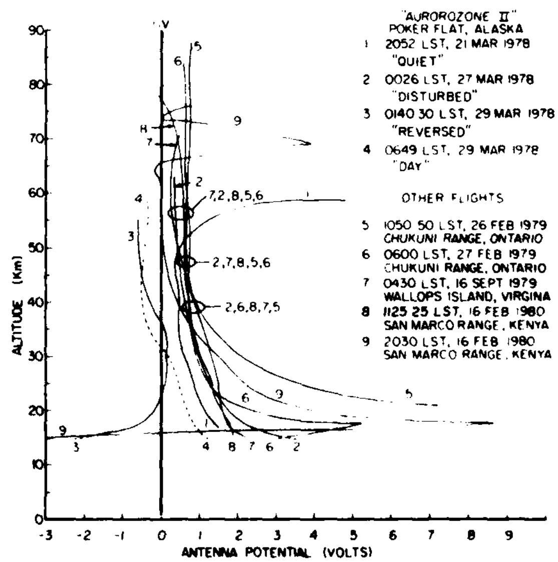

Figure 2. Antenna-to-payload potential; approximately equal to downward field in volts/meter.

9 reflecting lower cosmic ray ionization at low latitudes. The conductivity data from 8 was unusable below about 58 km due to the failed parachute. (The "blunt" probe geometry was clearly much more sensitive to velocity on this supersonic flight than the "slender" body electric field antenna.) It is noted that the electric field peak observed on flight 9 occurs just below a "ledge" in the conductivity profile in a region of relatively low conductivity, a situation similar to that observed elsewhere [Maynard, et al., 1981].

Discussion and Implications

Although we do not confirm the "permanent" maximum in electric field strength implied by the USSR data [Tyutin, 1976], we have observed a similar peak at a low latitude site (9) and probably the lower side of such a peak under high latitude "quiet" conditions (1). Subsequent measurements of a peak in the mid-latitude mesospheric electric field are reported in this issue [Maynard, et al., 1981]. Even when no pronounced peak appears, integrating the apparent residual electric field above 40 km gives a total voltage of several tens of kilovolts. We cannot say positively that this "baseline" effect is in fact real and not an artifact of the asymmetric geometry; however, a relative absence of this effect is observed on flights 1 and 9.

Assuming a passive middle atmosphere, the vertical conduction currents could be calculated by multiplying the fields of Figure 2 by the conductivities of Figure 3. However, since one of our conclusions is that there may be in situ generators in the middle atmosphere and we have no a priori way of distinguishing generator and load regions, this calculation must be approached with caution. We will simply mention that when this procedure is followed, the resulting inferred conduction currents (excluding the REP event data, 3 and 4) show much less difference in the stratosphere (X3 at 30 km) than the corresponding conductivities (X10). Except for curve 3 (the "reversal") the electric fields in the lower stratosphere decrease

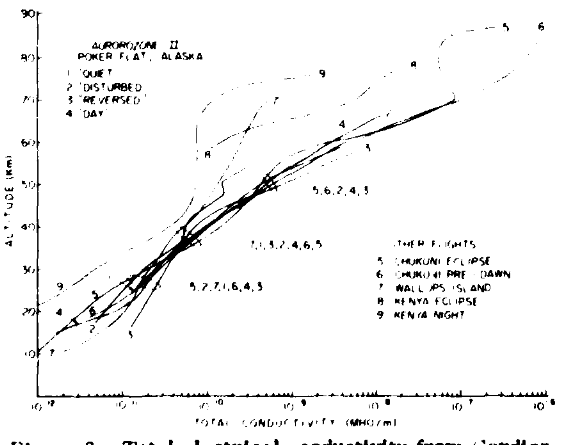

Figure 3. Total electrical conductivity from Gerdien condenser and blunt probe measurements.

with increasing altitude, although the magnitudes vary much more than "classical" theory would allow.

The most dramatic and identifiable auroral effect on the stratospheric electric field was the "reversal" which occurred during the REP event (curve 3). This event was characterized by much greater penetration of high energy particles to the lower mesosphere than the "disturbed" conditions of measurement 2 which had much more riometer absorption and visible aurora. Flight 3 also indicated the largest conductivity in the middle and lower stratosphere, showing that the effects of such events may penetrate very deeply. The reversal may be due to the field produced by the negative charge of the relativistic electrons.

Perhaps the most unusual data were obtained at night near the equator at the San Marco Range off the coast of Kenya (9). A peak in the mesospheric field was clearly observed, and integrates to about 10 kV. This would appear to be good evidence that the mesosphere is not always passive, but contains generators of emf, as it is difficult to see how such an effect could "map" from below or above and the conductivity profile does not support one-dimensional current continuity through a passive region. This measurement also indicates that the large mesospheric fields can occur at low latitudes where particle precipitation events are relatively weak.

The data presented here indicate that the middle atmosphere is electrically far more interesting than had been expected. Relatively large variations in both the conductivity and electric field profiles are seen. The electric field effects may be due to an "active" middle atmosphere, with internal sources of emf and relatively large circulating currents. The data here tend to support such a concept, particularly the large layered mesospheric electric field profiles observed by us and others. Although classical ionospheric dynamo processes driven by ion convection would not be expected to operate effectively as altitude decreases, due to the loss of influence of the magnetic field, this effect may be offset if the ions involved are aerosols or large clusters, as such dynamo processes are directly dependent on the momentum transfer cross section of the ions. In any event the fact that there are still poorly understood electrification processes in the troposphere would suggest that as yet unknown processes may operate in the relatively unexplored turbulent mesosphere.

It has been widely assumed previously that the middle atmosphere is passive in an electrical sense, with such a high conductivity that the global thunderstorm circuit is effectively confined to the troposphere and lower stratosphere [e.g. Israël, 1973]. Most views on modulation of this classical picture have focused on variations in the primary cosmic ray flux and/or the thunderstorm source [e.g. Markson, 1978], relatively rare deeply penetrating solar proton events [e.g. Holzworth and Mozer, 1979], and the "mapping" of high latitude ionospheric and magnetospheric fields through an electrically passive middle atmosphere [e.g. Volland, 1977]. Yet mid-latitude fair weather field data [e.g. Mühleisen et al., 1971; Reiter, 1977],

indicate a response of at least 10% in the vertical electric field and inferred local "ionospheric potential" to relatively modest and frequently occurring solar related events. An "active" mesosphere, with an associated potential of tens of kilovolts, might help to reconcile these data, as such a circuit could be easily modulated by radiation which penetrates to the mesosphere, a relatively frequent occurrence during geomagnetically disturbed periods.

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